# INTENSITY EFFECTS OF MONAURAL AND BINAURAL TEOAE SUPPRESSION

Capstone Project

Present in Partial Fulfillment of the Requirements for the Doctor of Audiology in the Graduate School of The Ohio State University

By

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## ABSTRACT

Transient evoked otoacoustic emissions (TEOAEs) were recorded in 14 young adult subjects with normal hearing using linear clicks presented at 45, 50, 55, 60, and 65 dB peSPL while continuous broadband noise was presented ipsilaterally, contralaterally, or binaurally at a constant level of 60 dB peSPL. Preliminary TEOAE suppression analysis was also completed on 3 older adults subjects with mild-moderate sensorineural hearing loss with linear clicks presented at 65 dB peSPL and broadband noise presented ipsilaterally, contralaterally, and binaurally at 60 dB peSPL. The young adult group demonstrated more TEOAE suppression in the binaural and ipsilateral conditions compared to the older adult group at 65 dB peSPL. In young adults, significantly greater TEOAE suppression was observed in the binaural noise condition compared to the ipsilateral and contralateral conditions across intensities. No significant change in the amount of suppression was observed as a function of click stimulus intensity level in the young adult group. The lack of significant changes in suppression magnitude in the binaural condition with stimulus intensity supports a hypothesis that previously observed decreases in binaural suppression with age are related to an MOC aging effect rather than

stimulus intensity differences. This finding may contribute to the difficulties hearing in noise and loss of the ‘binaural advantage’ often experienced by older listeners.

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VII MN: 7$^{th}$ Motor Nucleus

CANS: Central Auditory Nervous System

CN: Cochlear Nucleus

COCB: Crossed Olivocochlear Bundle

dB: Decibel

dBpeSPL: Decibel peak equivalent Sound Pressure Level

dB HL: Decibel Hearing Level

dBSL: Decibel Sensation Level

Hz: Hertz

IHC: Inner Hair Cell

IC: Inferior Colliculus

LOC/S: Lateral Olivococlear System

MS: Microsecond

MOC/S: Medial Olivocochlear System

OAE: Otoacoustic Emission

OCB: Olivocochlear Bundle

OHC: Outer Hair Cell

SOC: Superior Olivocochlear

SM: Stapedius Muscle

TB: Trapezoid Body

TEOAE: Transient Evoked Otoacoustic Emission

# CHAPTER 1: INTRODUCTION

Otoacoustic emissions (OAEs) are low level sounds emitted from the inner ear in response to stimuli, typically clicks or tone bursts, and are suggested to reflect the mechanical properties of a healthy cochlea and outer hair cells (OHCs). Otoacoustic emissions and can be measured non-invasively in the ear canal with sensitive microphones and are used clinically to evaluate the status of the cochlea (Bertoli & Probst, 1997; Parthasarathy, 2001). Numerous studies have demonstrated that the introduction of a secondary stimulus in the ipsilateral, contralateral, or both ears while measuring the OAE will lead to a change, typically a reduction, in amplitude of the OAE; this is referred to as OAE suppression (Collet et al., 1990; Veuillet et al. 1991; Berlin et al., 1995; Hood et al., 1996). The magnitude of OAE suppression is measured as the change in amplitude of the OAE following the onset of a suppressor stimulus, typically broadband noise. To date, the majority of OAE suppression research has been conducted using only a contralaterally evoked suppression stimulus. The use of a forward masking paradigm has allowed researchers to begin to investigate suppression with ipsilateral and binaural suppressor noise in addition to a contralateral suppressor (Berlin et al., 1995). Therefore, the relationship between TEOAE suppression in each suppressor condition still needs to be further examined. In addition, the majority OAE suppression studies have measured OAE suppression in young adults with normal hearing; little research has been done to investigate suppression of OAEs in the older adult population. The few studies that have investigated effects of age on OAE suppression have demonstrated reduced OAE suppression observed as a function of age (Castor et al., 1994; Hood et al., 1997; Parsarthy, 2001). In other words, the introduction of a broadband stimulus has less of a suppressive effect on OAE amplitude when measured in older adults compared to young adults. Hood et al. (1997) also demonstrated a greater reduction in the amount of OAE suppression observed in older adults in the binaural noise condition compared to the ipsilateral and contralateral noise conditions. Less suppression in the binaural condition has been suggested to correlate with the observed loss of the ‘binaural advantage’ with increased age and may contribute to the significant difficulties of hearing in noise frequently reported by the elder population (Kumar and Vanaja, 2004; Hood et al., 1997; Kim et al., 2006).

A potential problem in comparing OAE suppression between young and older adults is the differences in hearing sensitivity. For example, Castor et al. (1994) suggested the reduced OAE suppression they observed in older adult participants may have been a result in reduced audibility of the suppressor stimulus for their participants. Participants included in the older adult group in this study had some high frequency hearing loss; albeit OAEs were obtained (Castor et al., 1994). In this study, the intensity of the suppressor stimulus was maintained at a constant level across the younger and older adult participants. A constant suppressor stimulus level across subject groups with different hearing sensitivity may result in different suppressor noise sensation levels. Therefore, whether the less suppression observed in older adults was a result of true efferent system dysfunction or decreased effective stimulation of the medial olivocochlear system due to a decreased audibility is still in question (Castor et al., 1994).

The present study aimed to investigate the effects of stimulus intensity on transient evoked OAE (TEOAE) suppression in the ipsilateral, contralateral, and binaural noise suppression conditions in both young and older adults with normal hearing. The amount of suppression observed as a function of intensity in the binaural noise suppression condition will also be examined, a factor that has not been previously tested. We investigated the effect of the intensity of the click evoking stimulus, particularly the magnitude of suppression observed at near threshold levels. If the amount of suppression observed across intensity levels remained constant, we would infer the intensity of the OAE evoking stimulus has minimal effect on the amount of suppression observed in young adults with normal cochlear function. Further, a preliminary analysis compared suppression measured in older adults to verify that the lower levels of suppression observed in older adults is indeed a function of intensity or physiologic aging of the efferent system rather than differing sensation levels in the OAE evoking click stimuli. We hypothesized that no significant difference would be observed in the amount of suppression measured across intensity levels in any condition in the young adult group. We also suspect greater TEOAE suppression would be observed in the binaural noise condition at any intensity level. Finally, we hypothesized that young adult subjects would demonstrate greater TEOAE suppression than older adults subjects, with the greatest measureable difference in suppression in the binaural noise condition.

# CHAPTER 2: LITERATURE REVIEW

***Section one: Anatomy/physiology of the efferent system***

To fully comprehend TEOAE suppression, it is important to understand the anatomy and physiology of the efferent system. The central auditory nervous system (CANS) consists of two major neural pathways: the afferent pathways that relay information from the cochlea to the auditory cortex via the vestibulocochlear nerve (cranial nerve VIII), and the efferent pathway that carries information from the brain back to the cochlea. The functional role of the efferent pathway remains unclear, however current thinking suggests the efferent auditory system sends inhibitory signals to the cochlea and may even serve to modify the gain of the cochlear amplifier. Thus far, OAE suppression has been demonstrated to be a valuable, non-invasive tool to evaluate the function of the efferent system in humans (Hill et al., 1997).

The anatomy of the auditory efferent system is illustrated below in Figure 1. The efferent pathway to the cochlea consists of the olivocochlear bundle (OCB), which transverses between the two superior olivary complex (SOC) structures on each side of the brain (Hill et al., 1997). The crossed, contralateral OCB fibers cross the midline at the

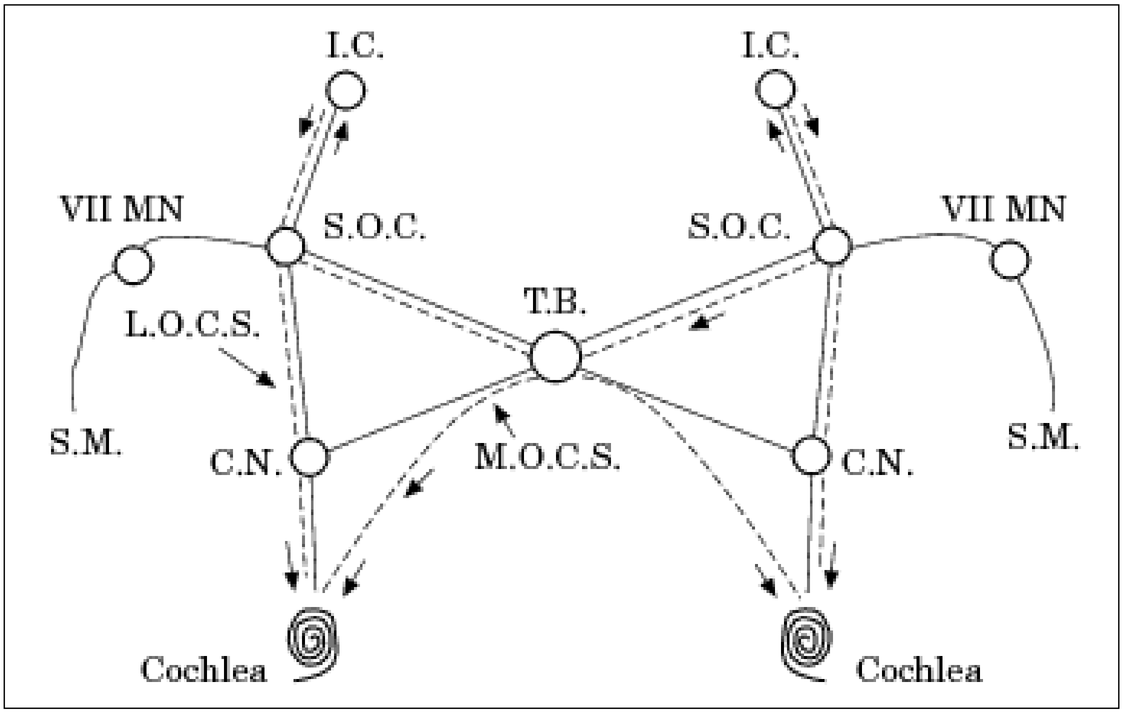


Figure 1. Image taken from Hill et al. (1997). Schematic demonstrating the pathway of the auditory efferent system to the cochlea (dashed line) and the afferent system. LOCS- lateral olivocochlear system, MOCS- medial olivocochlear system, CN-cochlear nucleus, SOC-superior olivary complex, TB- trapezoid body, IC-inferior colliculus, SM-stapedius muscle, VIIMN- seventh nerve motor nucleus

floor of the fourth ventricle and join with the uncrossed, ipsilateral OCB fibers (Hill et al., 1997). The efferent system consists of two main pathways, the lateral olivocochlear system (LOC) and the medial olivocochlear system (MOC) (Hill et al., 1997). The LOC originates in the lateral SOC and consists mostly of thin, unmyelinated and uncrossed fibers which originate on the ipsilateral side of the brain, travel through the vestibular nerve and terminate on the ipsilateral primary auditory neurons of the inner hair cells (IHC) (Guinan, 2006; Hill et al., 1997). The MOC pathway originates in the medial SOC and consists of thicker, crossed myelinated fibers that travel through the vestibular nerve and synapse in the contralateral cochlea on the outer hair cells (OHC) (Berlin et al., 1994; Guinan, 2006). Both pathways also project contralaterally to the cochlear nucleus and brainstem vestibular nuclei (Guinan, 2006). The myelination of the MOC fibers allows for easier analysis using both electrical and acoustic stimulation while the LOC fibers are unmyelinated and difficult to stimulate; consequently, little is known about the function and physiology of the LOC system (Guinan, 2006).

Sound transmitted to the cochlea travels along the tonotopically organized basilar membrane to the center frequency, or place of greatest stimulation, at which the OHCs serve to amplify the sound, referred to as the cochlear amplifier. The MOC efferent fibers synapse directly onto the axons of the OHCs and are suggested to play a role in modifying the action of the OHC by inhibiting the gain of the cochlear amplifier. This modification is reflected by a reduction in the amplitude of the OAE and is known as OAE suppression (Guinan, 2006).

Studies have been conducted to investigate the function of the efferent system with both electrical and acoustic stimulation in both humans and adults (Hill et al., 1997; Gifford & Guinan, 1987). Animal studies have demonstrated an inhibitory effect of the OCB on the action potential of the eighth nerve and mechanical activity of the cochlea and OHC following activation of the MOC with both acoustical and electrical stimulation (Hill et al., 1997; Gifford & Guinan, 1987). Gifford and Guinan (1987) electrically stimulated the efferent fibers of the crossed olivocochlear bundle (COCB) in the floor of the fourth ventricle in cats. Results demonstrated a decrease in the action potential of the auditory nerve (N1) in both the ipsilateral and contralateral cochleae. In this study, control lesions were also made along the midline in the floor of the fourth ventricle, where the COCB decussates. Following these lesions, no change was measured in the N1 potential with electrical stimulation. These control lesions demonstrate that COCB efferent fibers do indeed cause reductions in the N1 amplitude (Gifford & Guinan, 1987).

Henson et al. (1995) evaluated cochlear microphonic potentials in unanethesized mustached bats with contralateral acoustic stimulation. Tone pips were presented to the contralateral ear at 60-65 dB peSPL which was reportedly 5-10 dB below the thresholds for the acoustic reflex. Results demonstrated an actual decrease in the motion of the basilar membrane, measured by a change in the cochlear microphonic potential, following the onset of contralateral acoustic stimulation in the mustached bat. Authors also reported the response to contralateral acoustic stimulation is eliminated following a single injection of gentamicin (Henson et al., 1995). Henson et al. (1995) reported these results demonstrate clearly the role of the MOC system in modulation of the mechanical properties of the cochlea.

Critics of OAE suppression have suggested the observed reduction in OAE amplitude following the onset of acoustic stimulation may result from activation of the acoustic reflex. This hypothesis suggests acoustical stimulation activates both the OCB as well as facial nerve fibers that innervate the stapedius muscle. Specifically, onset of the acoustic suppression stimulus will lead to contraction of the stapedius muscle and in turn result in attenuation of the acoustic signal (Hill et al., 1997). This theory suggests that with activation of the acoustic reflex, the sensation level of the acoustic stimulus has been reduced leading to decreased OAE amplitude. However, multiple researchers have demonstrated the reduction or absence of TEOAE suppression in patients with lesions to the efferent pathway and/or SOC proving that the efferent system is responsible for this effect (Veuillet et al., 1991; Collet et al., 1990a; Berlin et al., 1995).

While investigating contralateral acoustic suppression, Veuillet and colleagues (1991) included three subjects with unilateral loss of the ipsilateral acoustic reflex with normal hearing thresholds. One subject had Bell's Palsy and two subjects had a surgical section of the stapedius muscle tendon. In all three patients, TEOAE suppression was still observed with the onset of contralateral acoustic stimulus and was not found to be statistically different than patients with an intact acoustic reflex. One subject even demonstrated greater suppression than most other participants included (Veuillet et al., 1991). Typically, the acoustic reflex is not activated until intensity levels reach minimally 70 dB peSPL, therefore intensity levels of the click and/or suppressor noise are not suspected to elicit acoustic reflex in most OAE suppression studies. Collet et al. (1990a) found a mean acoustic reflex threshold of 85 dB SPL in subjects with normal hearing thresholds (less than 10 dB HL). Further, Collet et al. (1990a) measured changes in OAE amplitude in 16 patients with unilateral deafness with the contralateral white noise ranging from 0 – 80 dB peSPL and found no change in OAE amplitude when the contralateral sound was presented to the hearing impaired ear. Further, Berlin et al. (1995) concluded that OAE suppression is typically greater for low intensity clicks and suppressor stimuli than for high intensity, again not consistent with activation of the acoustic reflex as a participating factor in OAE suppression.

As previously described, clear correlations have demonstrated a relationship between the auditory efferent system and changes in the response of the OHC following activation of the efferent system. The remainder of this paper will focus on defining this relationship further and investigating changes in the auditory efferent system with age.

***Section two: Stimulus Parameters of TEOAE Suppression***

Manipulations of OAE suppression test parameters have been demonstrated to have a significant effect on OAE suppression outcomes. Numerous studies have and continue to be conducted in order to identify ideal test parameters in the measurement of OAE suppression. Variables that affect OAE suppression include OAE evoking stimulus (clicks in this study), suppressor stimulus type (broadband noise in this study), non-linear versus linear evoking click, suppressor stimulus intensity levels, and click stimulus intensity levels, which is the dependant variable in this study. In respect to intensity level of the click evoking stimulus, it has been well-established that the overall amplitude of the OAE is dependent on the intensity of the evoking click stimulus; higher intensity clicks lead to greater amplitude OAE (Veuillet et al., 1991; Hood et al., 1996). However, Hood et al. (1996) also demonstrated that the overall amplitude of the OAE did not have a significant correlation with the amount of suppression observed.

*Part one: Intensity effects on TEOAE suppression*

Both the intensity of the OAE evoking click stimulus and the suppressor stimulus have been found to have significant affect on OAE suppression outcomes. Hood et al. (1996) investigated the effect of intensity level of both the contralateral white suppressor noise stimuli and the 80 microsecond (ms) click stimulus had on the amount of OAE suppression observed. The click stimulus intensity level ranged between 50 – 70 dB peSPL while suppressor noise varied from 10 dB below to 10 dB above the click stimulus in 2 dB steps. Results revealed that at a constant noise level, 60 dB peSPL, TEOAE suppression was greater for the lower intensity click stimuli, 60 dB peSPL and below, and less suppression was observed with high intensity clicks. At any given click intensity level, the amount of suppression increased systematically with the increase in white noise intensity level. Further, the amount of suppression observed was significantly greater when the contralateral white noise was 10 dB above the click level compared to 10 dB below the click level. Ultimately, the results of this study demonstrated that the amount of OAE suppression observed is maximized when the click evoking stimulus and noise suppressor stimulus are similar in intensity level or if the suppression noise is greater in intensity than the click evoking stimulus (Hood et al., 1996).

Hood et al. (1996) also compared absolute OAE amplitude to the amount of suppression observed at each click and suppressor noise intensity level. These results demonstrated a slight trend of greater OAE suppression observed when absolute OAE amplitude is more robust, however it was not suspected that the OAE amplitude had a significant effect on OAE suppression observed.

Veuillet et al. (1991) investigated effects of both the intensity of the evoking click stimulus and the intensity of the noise suppressor on the amount of OAE suppression observed. To evaluate the effect of click intensity level, the contralateral broadband suppressor noise was fixed at 50 dB peSPL while the click stimulus intensity was increased from 48 – 75 dB peSPL in 3 dB SPL increments. Veuillet et al. (1991) reported no significant change in the amount of TEOAE suppression observed at each click intensity level. These results are illustrated in Figure 2. The filled boxes represent the absolute amplitude of the TEOAE and the empty boxes represent the amplitude of the TEOAE following the onset of a contralateral broadband noise. Subsequently, the space between the boxes illustrates the change in OAE amplitude following the onset of the suppressor stimulus, also known as the amount of OAE suppression observed. It can be observed in the graph, that the greatest suppression occurs at the lowest intensity level of the ipsilateral stimulus. Veuillet et al. (1991) also demonstrated more OAE suppression as a function of increasing intensity level of the contralateral broadband noise stimulus when the evoking click stimuli held constant at 60 dB peSPL and the contralateral broadband noise randomly varied from 5-50 dB peSPL

Castor et al. (1994) investigated the change in TEOAE amplitude, described as equivalent attenuation, when using a white noise contralateral stimulus at 30 dB SL and non-linear clicks ranging from 60-72 dB peSPL in 3 dB peSPL steps. Although the SL was not specifically commented on, citations suggest SL was calculated as the intensity of the white noise suppressor stimulus in dB peSPL minus the subject's perceived white

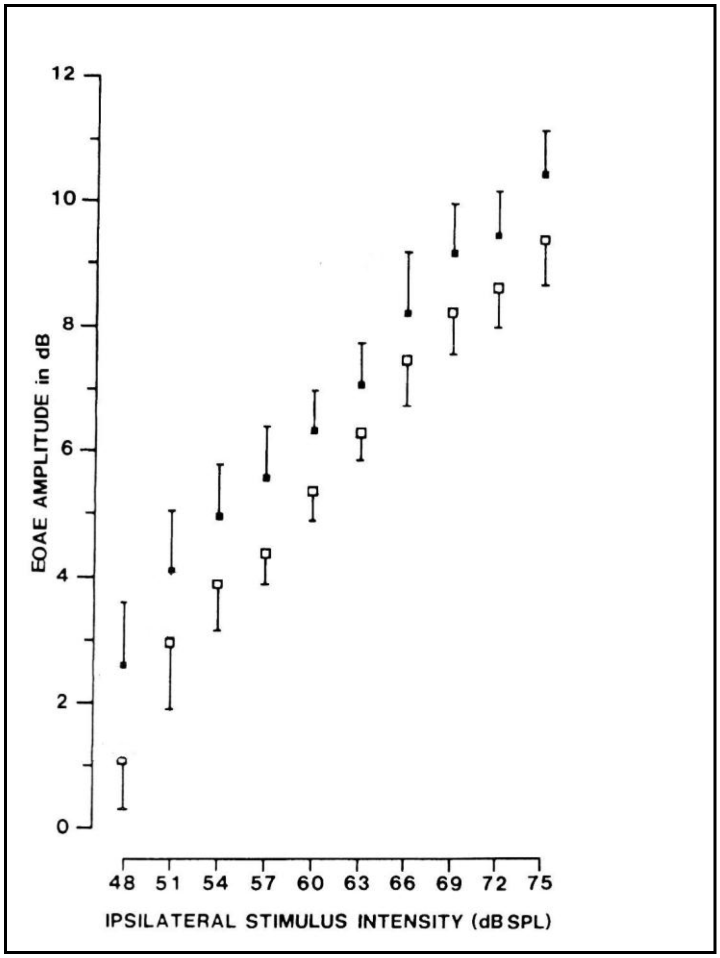


**Figure 2**. Taken from Veuillet et al. (1991). Comparison of mean amplitude with and without contralateral broadband noise.

noise threshold which is further described in Collet et al. (1990a). A significant reduction of overall TEOAE amplitude without a noise suppressor was found with increased age as well as significantly less TEOAE suppression in the older age group. Castor et al. (1994) maintained that these results are not correlated with the overall reduction in TEOAE amplitude observed in the older aged group. In this study, the investigators did not control for peripheral hearing loss. Thus, it cannot be ruled out that the lower amounts of observed TEOAE suppression in older adults cannot be attributed to a lower effective stimulus level for the older population compared to the stimulus level for the younger population rather than an effect of efferent dysfunction.

Parthasarthy (2001) demonstrated no significant difference in absolute TEOAE amplitude and a decrease in TEOAE suppression as a function of age. Investigators controlled for peripheral hearing loss by ensuring subjects all had thresholds equal to or less than 20 dB HL. In this study, the non-linear click stimulus was presented to the ipsilateral ear at 80 dB peSPL while the contralateral broadband noise suppressor was varied from 40 – 70 dB HL in 10 dB increments. In subjects older than 60 years of age, a dramatic decrease in the amount of OAE suppression is observed compared to the younger age groups. Additionally, increases in the contralateral broadband noise intensity level resulted in minimal changes in the amount of OAE suppression observed in the older adult group, whereas increases in the contralateral broadband noise suppressor stimulus resulted in a significant increase in the amount of suppression observed in the subjects younger than 60 years of age. Parthsarathy hypothesized these results are consistent with a decline in auditory efferent function with increased age. Figure 3, taken from Parthasarathy (2001), illustrates the average OAE suppression observed as a function of age and intensity level of the contralateral broadband noise suppression stimulus. The ordinate axis represents the level of suppression (in dB), each symbol represents a different intensity level of the contralateral broadband stimulus, listed in the legend key, and the abscissa separates the data by age groups. In the young adult subjects, more OAE suppression is observed with higher contralateral stimulus intensity levels, consistent with previous studies whereas in the 60-69 years and 70-79 years the least amount of suppression is observed and there is no significant difference in the amount of suppression observed with an increase in intensity of the contralateral broadband noise stimulus (Collet et al., 1990, Hood et al., 1996, Veuillet et al., 1991).

*Part two: Monaural vs. Binaural*

Berlin and Hood (1995) were the first to evaluate OAE suppression in conditions other than the contralateral noise suppression condition by utilizing a forward masking paradigm. An 80 ms click was presented at 65 dB peSPL and broadband noise at 60 dB peSPL. Results revealed a similar amount of OAE suppression observed when the suppressor noise was presented to the ipsilateral and contralateral ear and significantly greater TEOAE suppression when the broadband noise was presented binaurally. In an 1997 study, Hood et al. (1997) investigated changes in TEOAE suppression in subjects between 10 – 80 years of age, grouped in 10 year increments. Suppression was compared across ages in the binaural, ipsilateral, and contralateral noise conditions. Broadband noise was used as the suppressor stimulus and presented at a constant level of 70 dB peSPL. TEOAEs were evoked by 80 ms linear clicks presented at 65 dB peSPL. Results

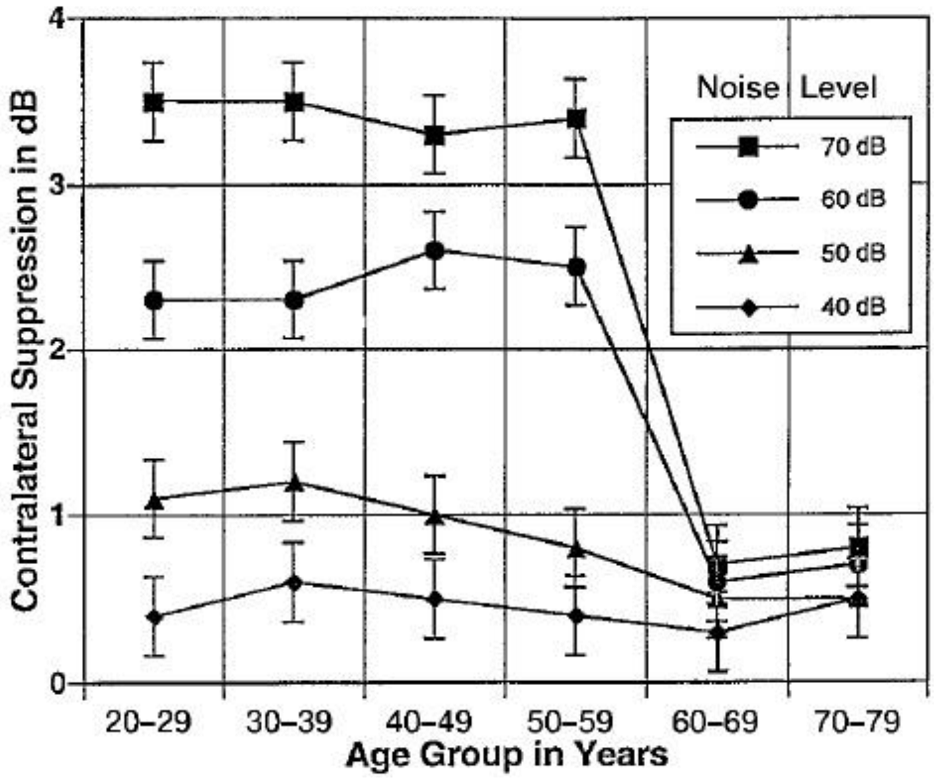


**Figure 3**. Taken from Parthasarathy (2001) Illustrates the effect of intensity level of contralateral noise suppressor and age on the amount of suppression observed.

from this study are illustrated below in Figure 4. TEOAE suppression is quantified on the ordinate access as the change in TEOAE amplitude in dB and age groups are displayed on the abscissa. Easily visualized in Figure 4, the greatest amount of OAE suppression was observed when the broadband noise was presented to both ears, the binaural condition, across all age groups. The amount of suppression observed in the ipsilateral and contralateral suppression noise conditions were less than the binaural condition and quantitatively similar. Consistent with previous studies, less TEOAE suppression was observed with increased age. This is the first study investigating aging effects of TEOAE suppression in any condition other than the contralateral condition.As demonstrated, minimal research has been done to evaluate the relationship of TEOAE suppression in the ipsilateral, contralateral and binaural conditions. However, current limited research has consistently demonstrated more OAE suppression is observed when the suppressor noise is presented binaurally than in one ear.

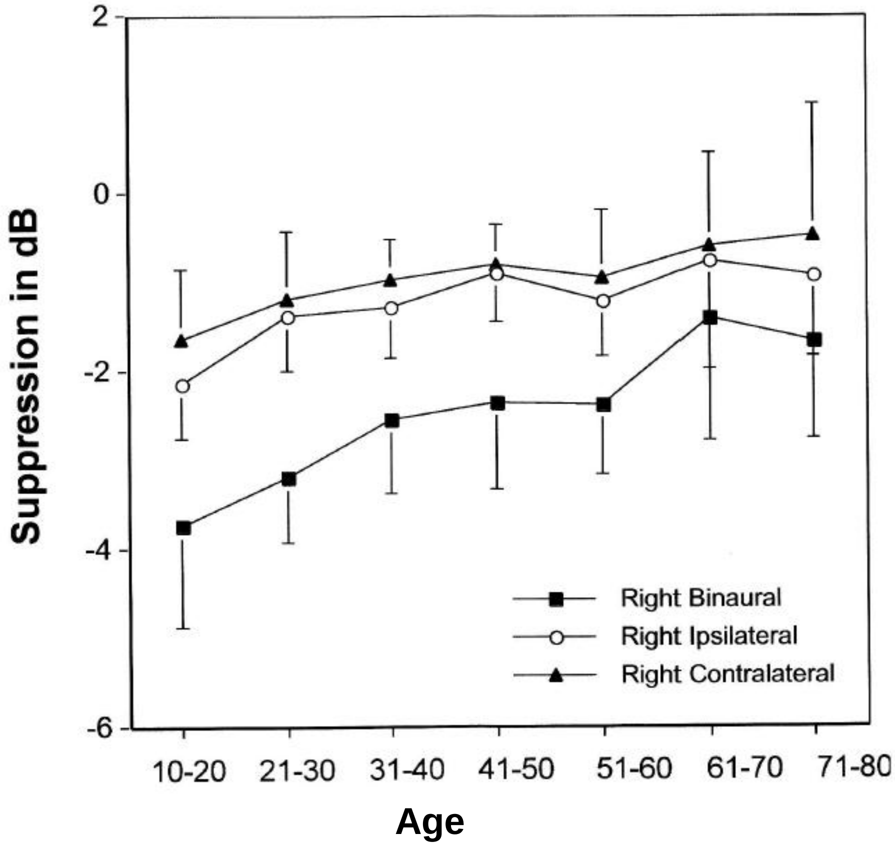


**Figure 4**. Hood et al. (1997) study. Illustrating the differences in OAE suppression observed in ipsilateral, contralateral and binaural noise suppression conditions as a function of age.

# CHAPTER 3: METHODS

***Subjects:***

*Young adult group:* Fourteen young adults, 11 female and 3 male, ages 21-31 years of age participated in the study. Inclusion criteria included present TEOAEs, defined as greater than 3 dB above the noise floor, at a minimum of three intensity levels at 45, 50, 55, 60, and 65 dB peSPL. Only seven of the fourteen subjects, all female, had present TEOAEs at the four desired intensity levels of 45, 50, 55, and 65 dB peSPL; further microanalysis was completed on these seven subjects. The ear with the higher amplitude OAE was selected as the test ear. All subjects had normal hearing defined as pure tone thresholds less than or equal to 20 dB HL for 250-8000 Hz, present ipsilateral acoustic reflexes, normal middle ear function demonstrated by normal tympanometry, and no significant history of noise exposure or neurological disorders.

*Older adult group:* Three older adult subjects, 2 female and 1 male, 60 – 62 years of age participated in the study. All subjects had normal middle ear function demonstrated by normal tympanometry. Two of the subjects exhibited hearing sensitivity within the normal range (thresholds less than 20 dB HL) for 250-4000 Hz with a decrease of hearing in the moderate hearing loss range for 8000 Hz in both subjects. The third subject included exhibited hearing sensitivity in the normal range for 250-3000 Hz with thresholds in the mild hearing loss range at 4000 Hz and moderate hearing loss range at 8000 Hz. Only one subject had present ipsilateral acoustic reflexes for 500-2000 Hz in the test ear. All older adult subjects denied significant history of noise exposure and/or neurological disorders.

*Click Stimuli:* TEOAEs were recorded using an 80 ms linear click presented at a click rate of 50/second through the standard probe of the Otodynamics ILO88 system. Linear clicks were defined in the Otodynamics ILO88 system as a group of four clicks of the same polarity and was used rather than the non-linear system (three clicks at the same polarity with the fourth click at a different polarity and intensity) in order to avoid distortion of the OAE (Hood et al., 1996). The goal was to obtain a TEOAE response greater than 3 dB at 45, 50, 55, and 65 dB peSPL. If a TEOAE was not present at 50 dB peSPL, TEOAEs were measured at 60 dB peSPL in order to obtain a response at three levels; this occurred in 3 subjects in the young adult group.

An average of 100 four-click trains or 500 single clicks was presented in each test condition. Stimulus level stability was measured as the comparison of the stimulus level recorded in the ear canal at the beginning of the run and monitored throughout the acquisition period; stimulus stability exceeded 80% in every run. Reproducibility of the OAE was measured as the correlation of half the sweeps stored in one memory buffer compared to the average of the other half of the sweeps stored in a separate buffer; reproducibility exceeded 70% in every run (Hood et al., 1996).

*Suppressor Stimulus:* A continuous broadband noise was presented ipsilaterally, contralaterally, and binaurally in the forward masking paradigm at a monitored intensity level of 60 dB peSPL (+/- 3dB). In the forward masking paradigm, the suppressor stimulus preceded the click stimulus by 10 ms and the suppressor duration was 400 ms (Hood et al., 1995). At each intensity level, a total of 9 runs were completed. This included three “control” runs measuring the TEOAE with the click stimulus only and no suppressor noise and six total runs measuring the TEOAE with binaural noise, ipsilateral noise, and contralateral noise; two runs were completed in each noise suppressor condition. The conditions were randomly interleaved for each subject in order to prevent order effect.

*Analysis:* The Kresge EchoMaster analysis program was used to analyze the data. In this program, the root mean square (RMS) difference was computed between the experimental (with noise) versus control (without noise) measurements to measure amplitude and temporal differences of the TEOAE (Berlin et al., 1993). The RMS amplitude value is a single number representing the average amplitude of the TEOAE response in the 8-18ms time period (Hood et al., 1996). Based on previous studies, suppression effects are greater in the 8-18 ms time period; an overall amplitude from the entire 20 ms time window typically grossly underestimates the suppression of effect in most subjects (Berlin et al., 1993; Collet et al., 1990).

Prior to being averaged, response amplitudes of the TEOAEs measured in each condition were compared to one another to assess run-to-run variability; this also helps to determine if the change occurred is indeed a change of the onset of a suppressor stimulus. Then, the mean RMS response amplitude and noise amplitude in the 8-18ms time period were calculated for the two responses in each condition. Suppression was calculated by subtracting the mean TEOAE amplitude from the with noise (binaural, ipsilateral, or contralateral) condition from the mean “control” TEOAE amplitude (without noise condition) in order to find the change in amplitude of the TEOAE with the onset of the suppressor noise, or the amount of OAE suppression (Hood et al., 1996).

*Procedure:* All testing was completed in a double-walled, soundproof booth during one experimental session that lasted approximately 2.0 hours. First, an audiologic evaluation including case history, pure tone audiometry, tympanometry and acoustic reflexes were completed to assess if the subject met inclusion criteria. If the subject met the previously described inclusion criteria, than TEOAEs were recorded from each ear using an 80 dB peSPL non-linear click at a click rate of 50/second with the Otodynamics ILO 88 system; the ear with the greatest amplitude TEOAE was used as the test ear for TEOAE suppression. After the test ear was chosen, the appropriate gain adjustment for broadband noise suppressor stimulus was assessed in the non-test ear; 60 dB peSPL suppressor stimulus level was utilized for all trials. TEOAEs were recorded with and without binaural, ipsilateral, and contralateral noise. The click stimuli were presented at 45, 50, 55, 60, or 65 dB peSPL and broadband noise was maintained at a constant level of 60 +/- 3 dB peSPL. Click intensity conditions and noise suppressor conditions were varied by participant in order to prevent order effect, with the exception of always starting and ending in the without suppressor noise condition. At each intensity level, TEOAEs were measured in nine total conditions; this included three “control” conditions, without suppressor noise, and two runs in each noise suppressor condition. Throughout testing, stimulus level stability and reproducibility were monitored as previously described. Analysis was completed using the Kresge EchoMaster analysis program as previously described.

# CHAPTER FOUR: RESULTS

Consistent with previous research, mean TEOAE amplitude increases as a function of click stimulus intensity level in both the with and without noise suppressor conditions (Veuillet et al., 1991; Hood et al., 1996). Figure 5 illustrates mean absolute TEOAE amplitude and +/- one standard error in each condition as a function of click stimulus intensity level in the young adult subjects. In the young adult group, all subjects were tested at either three or four intensities, depending on their TEOAE strength. Only two subjects were tested at 60 dB peSPL due to poorer responses for lower intensity stimuli and thus, had the lowest amplitude TEOAEs. Also note the greater variability for the 60 dB peSPL condition. In Figure 5, the distance between the black, square boxes and the other symbols represents the change in absolute amplitude of the TEOAE with the onset of the dedicated noise suppressor stimulus, also known as TEOAE suppression. It can be observed that the greatest change in absolute TEOAE amplitude occurred with the onset of the binaural noise suppression stimulus. Overall TEOAE amplitude could not be investigated across intensity in older adult subjects because TEOAEs could not be obtained at intensity levels below 65 dB peSPL

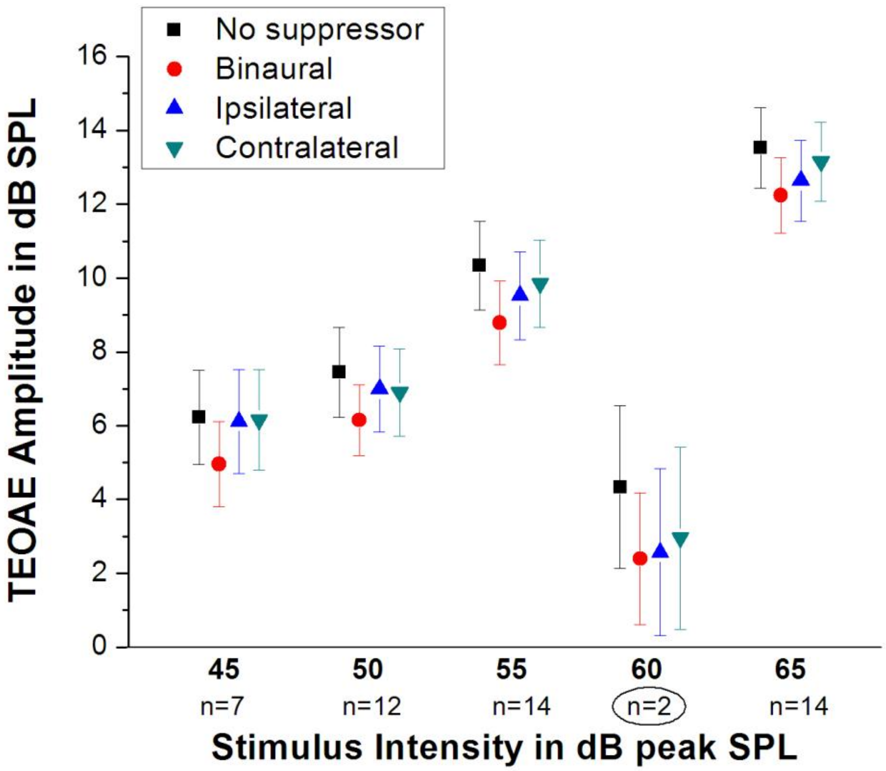


**Figure 5**: Illustrates absolute OAE amplitude (dB peSPL) as a function of click stimulus intensity. The black boxes represent absolute OAE amplitude without a suppressor stimulus; thus, the distance between the black box and each symbol represents the change in OAE amplitude at that intensity level with that suppressor stimulus, also known as OAE suppression.

| TEOAE Amplitude (dB peSPL) | | | | |
|---|---|---|---|---|
| | Without Noise | Binaural Noise | Ipsilateral Noise | Contralateral Noise |
| 65 dB peSPL | 13.76 | 12.47 | 12.89 | 13.40 |
| 60 dB peSPL | 4.33 | 2.39 | 2.57 | 2.95 |
| 55 dB peSPL | 10.98 | 9.19 | 9.88 | 10.21 |
| 50 dB peSPL | 7.44 | 6.15 | 6.99 | 6.90 |
| 45 dB peSPL | 6.22 | 4.96 | 6.11 | 6.15 |

**Table 1:** Numerical values of absolute TEOAE amplitude as a function of intensity and noise suppression condition.

When comparing absolute TEOAE amplitude across subject groups, the younger adult subject group demonstrated statistically significant greater absolute TEOAE amplitude (in dB) than the older adult subject group ($p<0.001$). The mean amplitude of the younger adult subject group was 13.68 dB and the mean amplitude of the older adult subject group was 6.39 dB. Figure 6 below, shows the mean TEOAE amplitude for both the younger adult and older adult groups with the 65 dB peSPL click stimulus; the error bars represent the +/- standard error for each group.

The greatest amount of TEOAE suppression was observed when the broadband noise was presented in the binaural conditions than both the ipsilateral and contralateral noise conditions, at all intensity levels. Figure 7 illustrates the amount of suppression observed as a function of intensity level in both the binaural, ipsilateral, and contralateral noise conditions for the younger adult subject group. Using a significance level of $p<.05$, significant differences were found between all suppressor conditions at 65 dB, between binaural-ipsilateral and binaural-contralateral at 55 dB, and binaural-ipsilateral at 50 dB. No significant differences were found at 45 dB. The 60 dB condition was not tested statistically due to the low number of subjects (n=2) at that level. Note the greater variability in suppression amplitude at the lower intensity levels. With exception of 60 dB peSPL, there were no significant differences measured across intensity level in any condition.

In the older adult subject group, TEOAE suppresion was only be investigated using a 65 dB peSPL stimulus level, as TEOAEs were not obtainable at lower intensity levels. Mean TEOAE suppression amplitude was 0.540 dB for binaural noise suppression condition, 0.533 dB for the ipsilateral noise suppression condition, and 0.617 dB for the

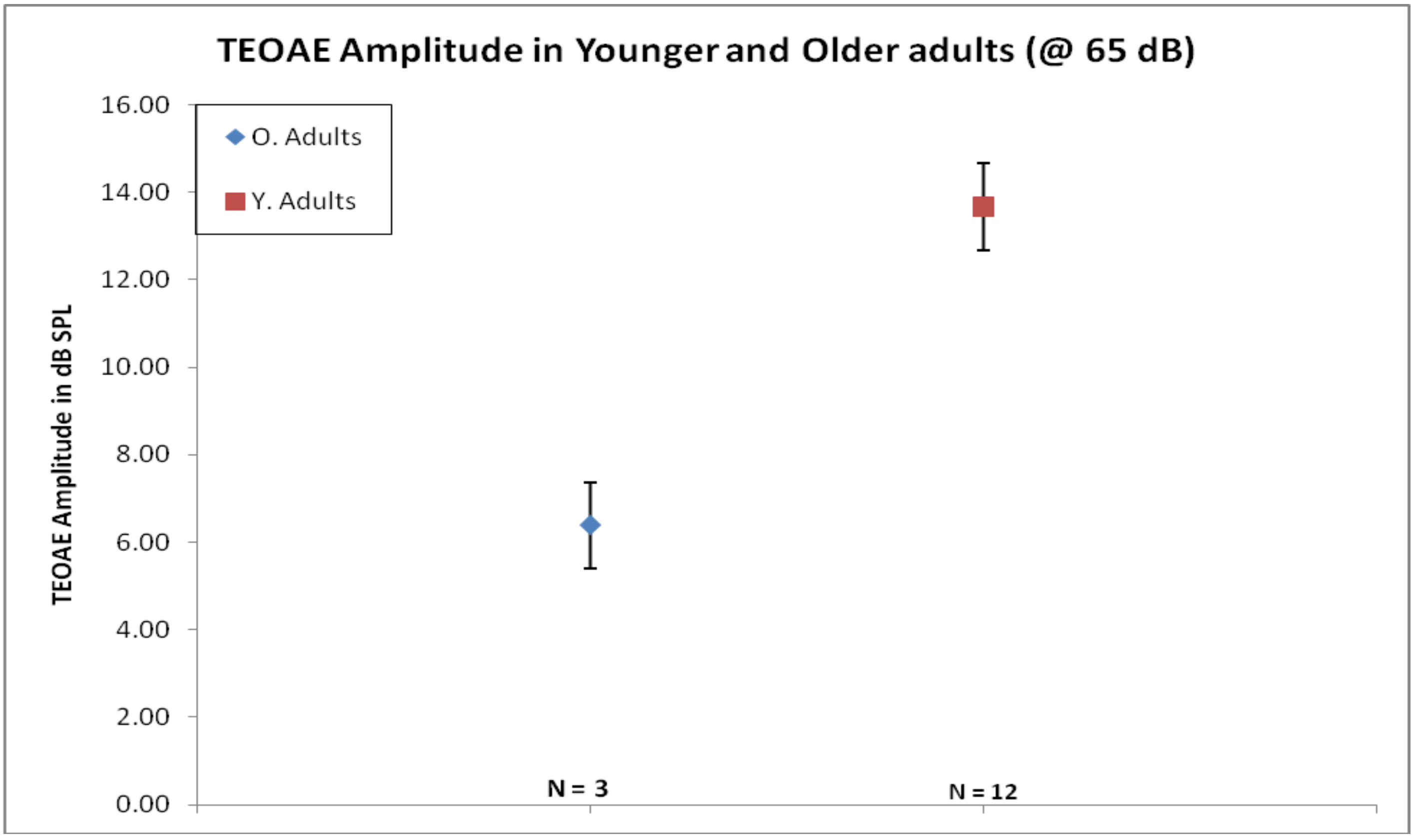


**Figure 6**: Absolute TEOAE amplitude for older adult subject group (blue diamond) and younger adult subject group (red square) with the 65 dB peSPL click stimulus.

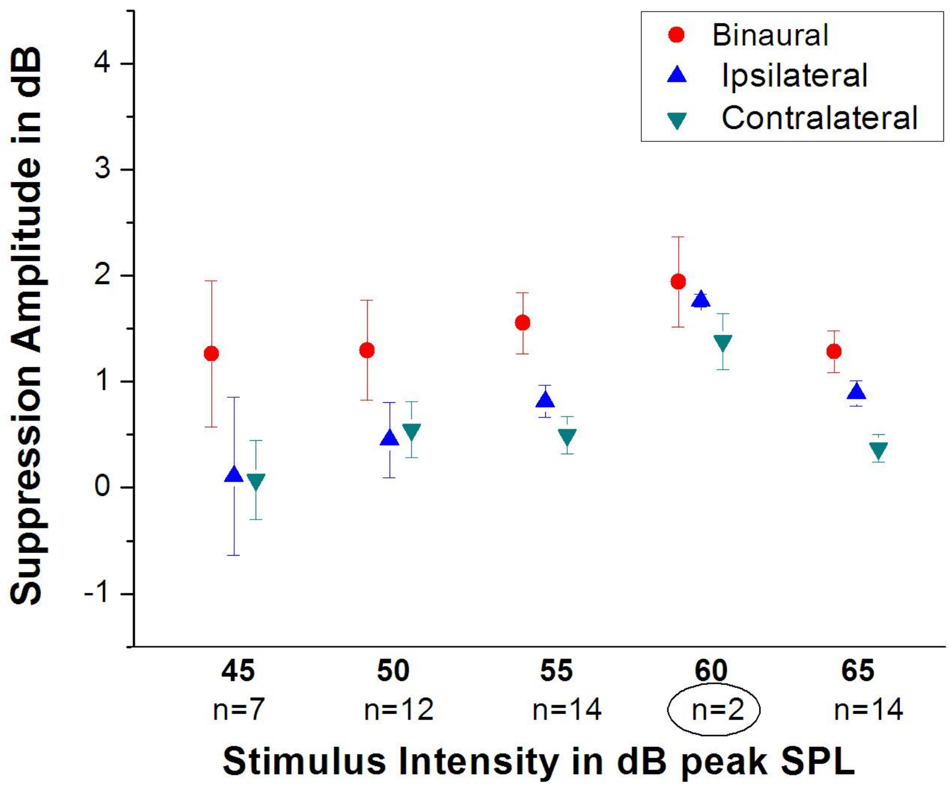


**Figure 7**: Illustrates suppression amplitude (dB) as a function of intensity for all subjects.

contralateral noise suppression condition. TEOAE suppression amplitude was not significantly different when comparing either binaural to ipsilateral or contralateral conditions ($p>0.05$). Figure 8 demonstrates the mean amplitude +/- standard error for each condition.

In the binaural and ipsilateral conditions, the young adult group demonstrated greater mean TEOAE suppression compared to the older adult group; however mean suppression amplitude differences were not found to be statistically different. In the ipsilateral noise suppression condition, the older adult group demonstrated slightly greater TEOAE suppression; however the small number of subjects in the older adult group should be taken into account. An important trend to observe is the large difference between the young adult subject group and the older adult subject group in the binaural noise suppression condition. The mean TEOAE suppression amplitude was 0.54 dB for the older adult group and 1.28 dB for the young adult group in the binaural noise suppressor condition. The mean TEOAE suppression amplitude was 0.53 dB in the older adult group and 0.87 dB in the younger adult group in the ipsilateral noise suppression condition. The mean TEOAE suppression amplitude was 0.61 dB for the older adult group and 0.37 dB for the young adult group in the ipsilateral condition. Figure 9 below illustrates mean overall TEOAE suppression amplitude in each condition for each population group, mean +/- one standard error are shown.

Statistical analysis was conducted for the 7 young adult subjects in which TEOAE suppression was assessed at four intensity levels (45, 50, 55, 65 dB); this data is graphed in Figure 10 below. In these subjects, binaural suppression again was consistently greater

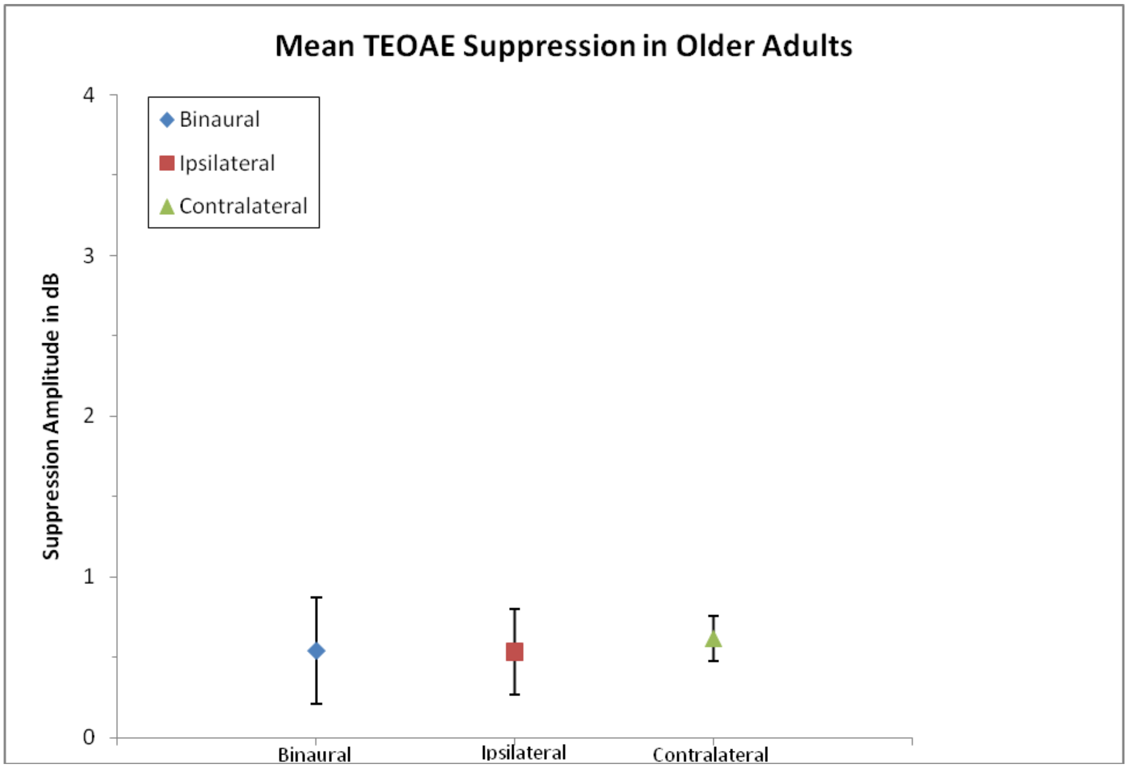


**Figure 8**: Illustrates the mean TEOAE suppression in each condition in the older adult subject group with the evoking click stimulus intensity of 65 dB peSPL. Suppression was not statistically significant across intensity levels in the older adult subject group.

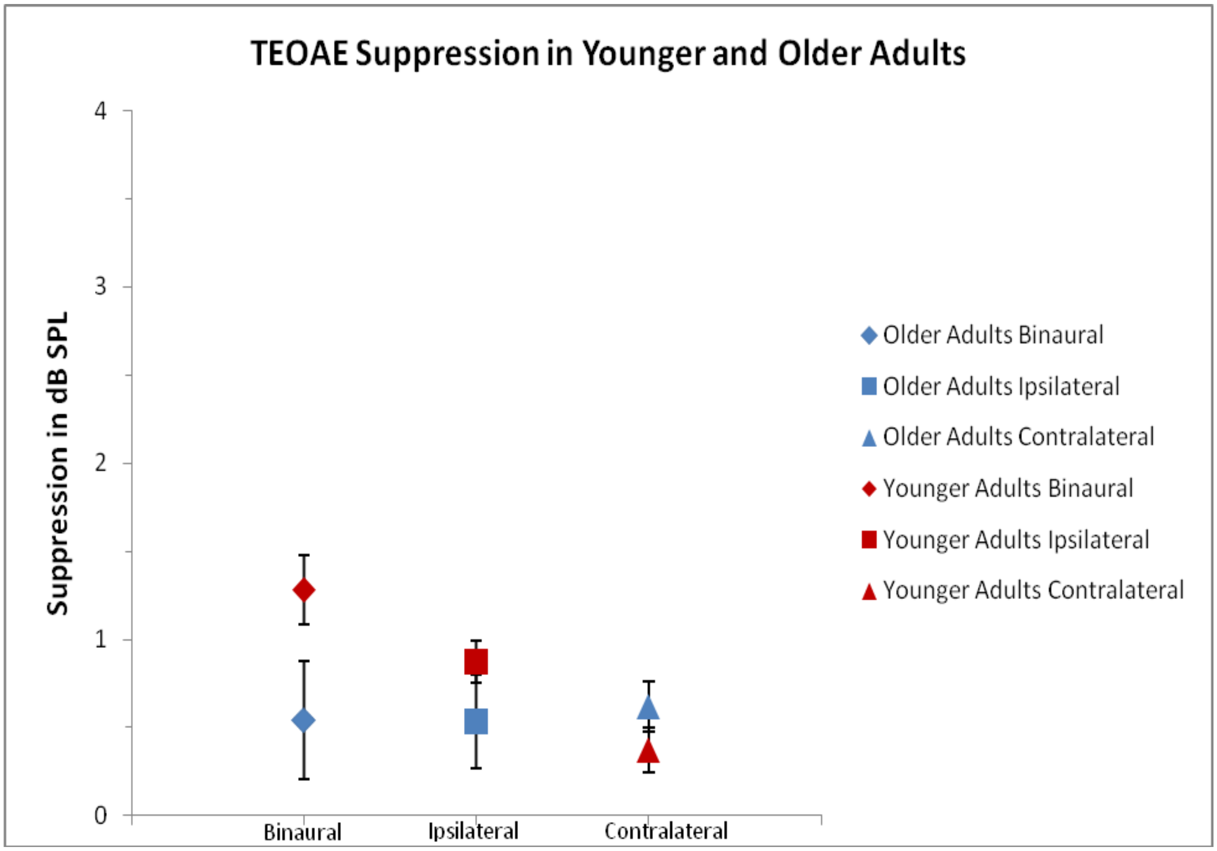


**Figure 9**: Illustrates the comparison between suppression in each condition across subject groups with the 65 dB peSPL click stimulus.

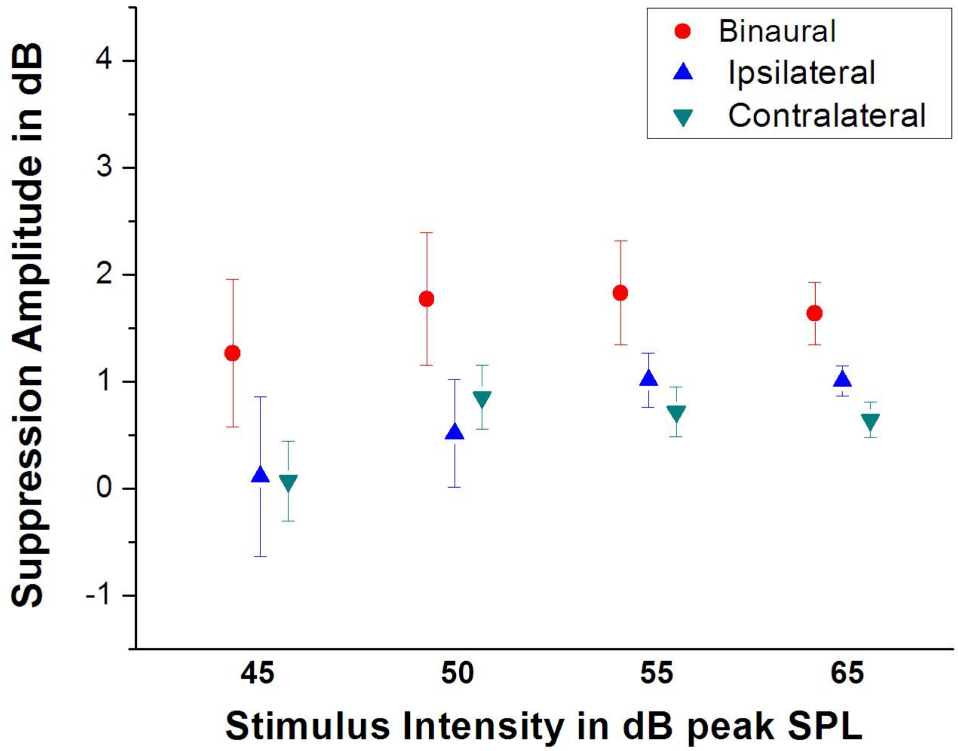


**Figure 10**: Mean TEOAE suppression as a function of intensity level on the 7 subjects who had present TEOAEs at all four intensity levels.

than both the ipsilateral and contralateral condition even at the lowest intensities. Suppression amplitude did not differ significantly across the intensities tested for either any of the suppressor conditions. Again, note the greater variability in suppression amplitude at the lower intensity levels.

# CHAPTER 5: DISCUSSION

As demonstrated in previous studies, the present study found that absolute TEOAE amplitude increased as a function of stimulus intensity in young adults (Veuillet et al., 1991; Hood et al., 1996). The effect of intensity could not be evaluated in older adult subjects, as TEOAEs were not able to be obtained at an intensity level less than 65 dB peSPL.

At a single click intensity level, the young adult subjects demonstrated a significantly greater absolute TEOAE amplitude than the older adult subjects included in this study. In agreement with these results, Castor et al. (1994) also demonstrated lower TEOAE amplitude in the older adult subjects; however, both studies included older adult participants with hearing loss. Parthasathy (2001) previously demonstrated no significant difference in absolute TEOAE amplitude between young adult subjects and older adult subjects. However, Parthasarthy (2001) included only subjects with audiometric thresholds better than 20 dB HL while the preliminary data in this study included subjects with mild, high-frequency hearing loss. Poor audiometric thresholds are expected to contribute to the lower TEOAE amplitude observed in the older adult subjects included in this study (Bertoli & Probst,. 1997).

In agreement with Castor et al. (1994) and Parsarthy (2001), less OAE suppression was observed in the older adult subject group compared to the younger adult group. Castor et al. (1994) and Parsarthy (2001) evaluated TEOAE suppression using only contralateral noise, while this study demonstrated less TEOAE suppression in both the binaural and contralateral noise conditions.

In the young adult subjects, the greatest amount of suppression was observed in the binaural noise condition at all intensity levels. Suppression amplitude did not vary significantly across intensity level in any noise suppression condition. These results suggest that in young adults, intensity level does not play a role in the total amount of suppression observed. Thus, even at near threshold intensity levels, the amount of TEOAE suppression observed remains relatively constant in young adults. In relation to Hood's 1997 study, the reduced suppression observed in older adult subjects is likely a result of efferent system dysfunction rather than an effect of signal intensity level. Further, this study revealed a greater decline in the amount of suppression observed in the binaural condition compared to the monaural noise suppressor conditions; this is hypothesized to play a role in diminished ability for signal detection in noise and possibly the loss of "binaural advantage" often described in older adult patients (Scharf et al., 1997). For example, Scharf et al. (1997) demonstrated a correlation in listeners' with normal hearing ability to detect tones in noise and otoacoustic emission suppression. Meaning, patients with greater otoacoustic emission suppression demonstrated a greater ability to detect signals in noise than those with poorer OAE suppression (Scharf et al., 1997).

Kumar and Vanaja (2004) evaluated speech identification tasks at 50 dB HL in the presences of ipsilateral broadband noise, contralateral broadband noise, and binaural noise in children ages 10-12 years with normal hearing (thresholds below 15 dB HL). Results of this study demonstrated improvement in speech identification tasks when the ipsilateral noise was presented at a +10 and +15 dB signal to noise ratio and the contralateral broadband noise was maintained at 30 dB SL (re: noise threshold). the children performed poorer at these speech identification tasks when there was no noise present in the ipsilateral ear and/or no noise present in the contralateral ear. Kumar and Vanaja (2004) also found a significant correlation between the amount of improvement in the speech identification task with the presentation of binaural noise and the strength of the child's contralateral TEOAE suppression. Authors of this study suggested these results support the argument that MOC system aids in signal detection in noise ability.

Kim et al. (2006) assessed auditory efferent system function by measuring OAE suppression using distortion product OAEs (DPOAE) and contralateral wideband noise presented at 30 dB SL relative to the participant's threshold for the noise. In this study a significant correlation was found between the amount of contralateral DPOAE suppression observed and the subjects' ability to complete the Hearing in Noise Test (HINT) at a 0 degree azimuth. Kim et al. (2006) also suggested these results are related to an age-related dysfunction of the auditory efferent system. Both of these studies contribute to the mounting research that the auditory efferent system plays a role in the ability to hear and understand in noise and have demonstrated correlations between understanding in noise and the functioning of the auditory efferent system.

Hood (1997) reported a greater decline in the amount of suppression observed with increased age in the binaural noise suppression condition relative to ipsilateral and contralateral noise suppression conditions. One lingering question in all OAE aging studies is whether slight/mild high frequency hearing loss results in reduced stimulus intensity level and thus reduced OAE suppression or if the reduced suppression is indeed a result of physiologic aging effects of the auditory efferent system. One of the goals of this study was to evaluation TEOAE suppression and near thresholds intensity levels in young adults with presumably normal auditory efferent systems and investigate the effect on the amount of OAE suppression observed. The results of the present study suggest that this effect may be an effect of age rather than a byproduct of slightly decreased sensation level of the stimuli due to mild, high-frequency hearing loss and contributes to the mounting research that supports the hypothesis that the auditory efferent system may aid in signal discrimination in noise (Hill et al., 1997).

Results of this study suggest that TEOAE suppression magnitude remains relatively constant across intensity level for both monaural and binaural suppression conditions and supports the hypothesis that the decrease in binaural suppression observed in older adults is consistent with an aging effect of the efferent system. These findings support the observed difficulties of older listeners in noise and the loss of the binaural advantage with age. One limitation of this study is the small number of older adult participants and that older adult participants included in the study had hearing loss. Future studies investigating TEOAE suppression should include older adult participants with normal hearing thresholds.

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